Katharina Loot*, Oliver Waletzko, Ralf Rohn, Bernhard Spaan and Andreas Block

Analysis of resolution properties for three generations of MV imagers in radiation therapy using the modulation transfer function

Abstract: Imaging in radiation therapy has become an important part of clinical routine. In order to evaluate and compare the image quality of verification images from different imaging modalities, one needs objective criteria like the modulation transfer function (MTF). The aim of our study was to compare the resolution properties of three generations of electronic portal imaging devices (EPIDs), namely one fluoroscopic-optical system and two different flat-panel imaging systems.

Keywords: portal imaging, modulation transfer function, image quality.

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1 Introduction

Megavoltage (MV) imaging has evolved alongside radiation therapy, moving from film verification to electronic portal imaging devices (EPIDs) which nowadays offer support with patient positioning as well as dose verification. Due to the high photon energy present, EPIDs cannot provide the high image quality known from diagnostic radiology. On the other hand, the EPID must satisfy quite different demands. In the long term, we want to learn how measured quantities such as spatial resolution and noise will effect observed qualities like low contrast detectability.

For any imaging system, the quantitative analysis of image quality draws on universal concepts developed for signal processing and communication theory. The imaging system and each individual component in the imaging chain are interpreted as linear and shift-invariant [1]. We can characterize the system by analyzing the relationship between input and output signal.

In this work, we will determine the spatial resolution properties of three EPIDs by measuring their modulation transfer function (MTF). The MTF maps the transfer of contrast (or modulation) as a function of spatial frequency. We measure the presampled MTF, which takes into account the entire detection process before the sampling of the signal.

2 Material and methods

In a preceding analysis, we developed a reliable method for MTF measurement of EPIDs. Starting point was the IEC 62220-1 protocol [2], which describes the MTF measurement of kV systems in diagnostic imaging. The phantom consists of a tungsten plate with a polished edge, which is placed directly on the detector surface to create an input signal with step function characteristics. The measured edge spread function (ESF) is differentiated and Fourier transformed to yield the presampled MTF.

To adapt this method to the changed beam spectrum, we introduced the following modifications: The phantom was not placed in direct contact with the detector, but positioned 10cm in front of the detector surface [3]. We strongly recommend to detrend all images by fitting a two-dimensional polynomial to the image of an open field (as suggested in [2]), otherwise the intensity distribution of the beam will cause serious distortions of the ESF. It was not necessary to linearize the image data before processing, as our EPIDs showed a strictly linear relationship between

***Corresponding author: Katharina Loot:** Technische Universität Dortmund, Experimentelle Physik 5, 44221 Dortmund, Germany, e-mail: katharina.loot@tu-dortmund.de
Oliver Waletzko, Ralf Rohn: Praxis für Strahlentherapie am Klinikum Dortmund, Germany, e-mail: praxis.ralf.rohn@klinikumdo.de
Bernhard Spaan: Technische Universität Dortmund, Experimentelle Physik 5, Germany, e-mail: bernhard.spaan@tu-dortmund.de
Andreas Block: Klinikum Dortmund, Institut für Medizinische Strahlenphysik und Strahlenschutz, Germany, e-mail: andreas.block@klinikumdo.de

deposited charge and resulting grey values. The MV images contain a significant amount of noise, which subsequently introduces noise in the MTF but does not influence the shape of the MTF. Therefore, we acquired up to 100 consecutive frames, which were averaged in order to produce a less noisy edge spread function for MTF analysis.

We investigated the following three EPIDs:

- System A: TheraView by Cablon Medical, fluoroscopic-optical system with CCD camera, 512px x 512px, 0.78 mm pixel spacing, 1.5 mm brass plate + 400 mg/cm^2 Gd_2O_2S screen, linear accelerator: GE Saturne 43
- System B: PortalVision aS500 by Varian, first generation flat panel imager, 512px x 384px, 0.78mm pixel spacing, 1 mm copper + 134 mg/cm^2 Gd_2O_2S screen, linear accelerator: Varian Clinac 2100
- System C: PortalVision aS1200 by Varian, latest generation flat panel imager, 1280px x 1280px, 0.34mm pixel spacing, 1 mm copper + 134 mg/cm^2 Gd_2O_2S screen + backscatter shielding, linear accelerator: Varian VitalBeam

All images were acquired using 6 MV photons, the geometrical proportions such as source-to-phantom and source-to-detector distance were kept constant for all accelerators. The MTF analysis software was written using Mathematica (Wolfram Research).

3 Results

We calculated the presampled MTFs for the camera-based and both flat panel detector systems as described above. **Figure**
shows a comparison of the MTFs (System A in black, System B in green, System C in blue).

The range of spatial frequencies for which the MV imaging systems show significant transmittance is limited to about 1 mm^{-1}.

The MTF of the camera-based system A exhibits lower values than that of the flat panel systems B and C for the entire spatial frequency range. The MTF drops to 50% at 0.16 mm^{-1} and reaches 20% at 0.35 mm^{-1}.

The first-generation flat panel imager B shows the highest values in the frequency range up to 0.4 mm^{-1}. The MTF reaches 50% at 0.26 mm^{-1} and 20% at 0.62 mm^{-1}.

The currently produced flat panel imager C shows the most balanced MTF, with moderate results for lower spatial frequencies but the highest values for spatial frequencies

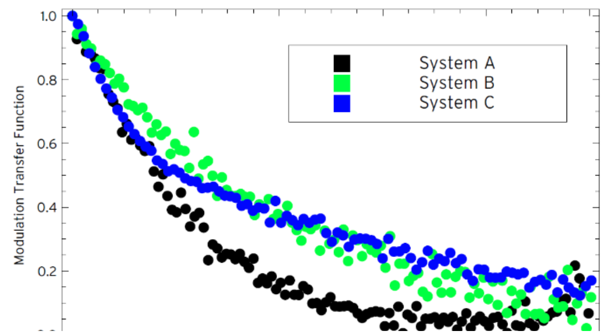

Figure 1: Presampled modulation transfer function of the three analyzed EPIDs.

above 0.4 mm^{-1}. The MTF shows 50% at 0.20 mm^{-1} and 20% at 0.80 mm^{-1}.

4 Discussion

Most striking is the fast decline of the MTF of system A. This imaging system converts the high-energy photons into optical photons by means of a metal plate and a phosphor screen (scintillator). The optical photons are directed to a CCD camera by a mirror set at a 45° angle, so as not to expose the CCD directly to the MV beam. Systems B and C generate the optical photons similar to system A. The photons are subsequently detected by an array of photodiodes implanted on an amorphous silicon panel placed in direct contact with the phosphor screen. From these technical details about the detection process, we can explain the differences in the MTFs. All three systems suffer from the spread of high-energy particles and optical quanta in the phosphor screen, leading to an overall low limiting resolution. In addition, the resolution of System A is deteriorates further by the spread of optical quanta in the camera lens. This is in accordance with previous works, which showed that the lens significantly degrades the image quality for high spatial frequencies [4]. The flat panel imagers profit from the close proximity of the photodiodes to the scintillator.

The MTFs of systems B and C show a similar behavior, but system B is better suited for the transfer of lower spatial frequencies.

On the other hand, system C shows an optimized contrast transfer for higher spatial frequencies. There are two differences in the detector design to which we can attribute this improved performance. Firstly, the thickness of the phosphor screen is reduced from 0.34 mm for system B to 0.29 mm for system C. A thinner scintillator allows less spreading of photons and improves the spatial resolution.

Secondly, system C features an additional backscatter shielding (consisting of aluminum and lead) to prevent irregular scatter from the support arm of the detector. Both modifications lead to the improved contrast transfer of 20% at 0.8 mm^{-1} spatial frequency, which coincides with previously published data [5].

This development allows the reasonable use of a smaller pixel spacing: We have analyzed the signal transfer up until, but not including, the sampling stage. Sampling deteriorates the resolution further, as the image signal is averaged over the area of one pixel. It also introduces the undesirable effect of aliasing. When choosing a suitable pixel size Δ, the spatial frequency content of the signal should be approximately band-limited to the Nyquist frequency $1/2\Delta$. To match the improved transfer properties of system C, the pixel spacing was down-sized to 0.34 mm, which results in a Nyquist frequency of 1.5 mm^{-1}. In comparison, systems A and B are not expected to transfer frequencies higher than 0.6 mm^{-1}, judging by the pixel spacing of 0.78 mm in both cases. Thus, the improved signal transfer at higher spatial frequencies is well matched with the smaller pixel spacing.

Our results document that there has been a steady improvement in the MTF with each successive imager generation. Further research needs to investigate the noise transfer properties of the system in a similar fashion. Our long-term goal is to correlate these physical quantities with the diagnostic image quality.

Author's Statement

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